ELSEVIER

International Journal of Psychophysiology 28 (1998) 77–98

INTERNATIONAL JOURNAL OF PSYCHOPHYSIOLOGY

On the intercorrelation of some frequency and amplitude parameters of the human EEG and its functional significance. Communication I: Multidimensional neurodynamic organization of functional states of the brain during intellectual, perceptive and motor activity in normal subjects

Vladimir V. Lazarev[a,b*]

[a] *Laboratory of Neurophysiology, National Mental Health Research Centre of the Russian Academy of Medical Sciences, Moscow, Russia*

[b] *Laboratory of Clinical Neurophysiology, Instituto Fenandes Figueira, Oswaldo Cruz Foundation and CNPq / FIOCRUZ convention, Rio de Janeiro, Brazil*

Received 10 January 1996; revised 21 July 1997; accepted 27 August 1997

Abstract

In 95 normal subjects, a separate evaluation of the amplitude and frequency parameters of EEG by period analysis made it possible to reveal, using factor analysis, four independent groups of parameters — the EEG factors, two of which being independent of the amplitude fluctuations. They were considered as integral EEG characteristics of qualitatively different neurophysiological processes. Decrease of Factor I values during mental activity (called 'general activation') reflected an intercorrelated desynchronization of the wave amplitudes in all the bands, a decrease of α-index (percentage presence in epoch) and regularity together with parallel increase of the indices and mean periods of Δ- and θ-waves. This generalized reaction has shown 'non-specific' dependence upon novelty and difficulty of the tasks and stimuli with certain task-specific topographical distribution. An increase of values of regional Factor Ia in the anterior areas was caused by Δ- and θ-amplitude synchronization, more pronounced during matching the rhymes (MR) than in mental multiplication (MM). An increase of Factor II values (related to increase of the index, frequency and regularity of β-activity and called 'cortical excitation', CE) was more expressed during MR, whereas an increase of Factor III values (an increase of mean α-period and θ-index called 'active selective inhibition', ASI) was characteristic of MM, the latter reaction being evident in the right hemisphere. During analysis

* Laboratory of Clinical Neurophysiology, Instituto Fenandes Figueira, FIOCRUZ, Av. Rui Barbosa 716, Flamengo, Rio de Janeiro, RJ, 22250-020, Brazil. e-mail: vladimir@sinfo.iff.fiocruz.br

0167-8760/98/$19.00 © 1998 Elsevier Science B.V. All rights reserved.
PII S0167-8760(97)00068-8

of external sound stimuli and rhythmical clenching of a fist, an increase of Factor III values; was accompanied by decrease of Factor II values in the motor activity; such reciprocal reaction being localized in the central areas contralateral to the hand moved. Neuropsychological analysis suggests that CE correlates with associative and successively organized mental operations involving search for memory traces and ASI presumably relates to different aspects of mental selectivity such as simultaneous mental operations, voluntary attention and mental automation, the latter two cases being supported by parallel reduction of CE. © 1998 Elsevier Science B.V.

Keywords: EEG period analysis; Factor analysis; EEG activation; Structure of functional state of the brain; Neuropsychology; Mental activity; Voluntary attention; Mental selectivity; Internal inhibition; Interhemispheric asymmetry

1. Introduction

In the psychophysiological study of mental activity, the neuropsychological criteria of experimental tests during EEG registration seems to be a productive way to approach the problem of correlation between psychological and physiological phenomena. It can provide more adequate 'brain-oriented structuring' of mental processes into units that are more likely to find expression in certain task-dependent changes in the EEG. These units can relate to certain specific functional features of different cortical areas with different and particular types of organization of mental operations based on different 'physiological factors' (Luria, 1966). At present, a neuropsychological approach in EEG investigations is growing more popular (Khomskaya, 1972; Lazarev et al., 1977a and b; Gruzelier et al., 1988; Lazarev, 1989; Gruzelier et al., 1990).

In order to reveal finer and specific EEG reactions related to these 'factors', the principle of 'contrast' psychological testing seems promising. Two or more types of contrasting tasks (usually more or less similar in neuropsychological structure) are presented to the subject during the same experiment. Each type calls for activity of some specific topographically different cortical area or demands some special organization of mental operations, from a neuropsychological point of view, together with elements common to all the tasks employed. Direct comparison of such contrasting EEG data accentuates the task-specific features of EEG patterns peculiar to each contrasting type of mental activity. In our previous work, such an approach has made it possible to obtain task-dependent and physiologically significant differences between closely similar types of intellectual, perceptive and motor activity in a range of EEG studies: 50-channel electroencephaloscopy (Livanov, 1977) of the distance synchronization of biopotentials (Lazarev et al., 1977a; Lazarev, 1978), spectral power mapping (Lazarev, 1992) and evaluation of the factor structure of parameters from EEG period analysis (Lazarev, 1986b, 1988, 1989).

Experience with different types of EEG analysis has shown that a search for any cerebral 'physiological factors' of higher mental processes requires very sensitive EEG indicators, able to reflect quite fine changes in the functional state of the brain which are related to the mental activity studied. In our view, none of the methods cited above, nor others known from the literature are universal enough to show a complete set of such changes — which is not surprising, considering the complicated object of study. Each of the approaches accentuates some specific aspects of brain function and not others, with the most suitable method depending on the particular task and experimental condition. A combination of approaches should therefore be investigated as well.

Methodological problems arise in EEG evaluation of functional states of the brain during neuropsychological testing, with complex tasks that are very often quite similar to real-life thinking. It is usually difficult to subdivide such mental processes into short time-locked elementary perceptive acts, reactions or specific mental operations. Under these experimental conditions, it is

only possible to evaluate average modes of the brain's functioning over quite long epochs (from seconds to minutes between the beginning and the end of task) by time-average parameters from ongoing scalp EEG. In task-dependent changes of characteristics of EEG spectra, for example, a non-homogeneity of local functional state of the brain (registered by a single derivation) can be observed as an increase or reduction of spectral power in different frequency bands with varying topographical distribution (Ray and Cole, 1985; Etevenon, 1986; John et al., 1989; Keirn and Aunon, 1990; Lazarev, 1992; Fernandez et al., 1995). These reactions may relate to functionally different neurophysiological processes, which are not equally expressed in all cortical areas. This enabled some authors to suppose that different EEG frequencies are connected with different cognitive processes (Klimesch et al., 1994).

The problem of complex structure of the local functional state of the brain in relation to mental activity is thus evident. In psychophysiological experiments, adequate EEG analysis should be aimed at the separation of functionally different, but coexisting neurophysiological processes related to qualitatively different aspects of cerebral organization of higher mental activity. This problem is usually explored by spectral analysis. However, do these aspects correlate only with the 'power' measurements of EEG oscillations (which spectral analysis is aimed at) or may they be expressed purely by their frequency characteristics, irrespective of the amplitude fluctuations? This question arises from the following observations.

The main physiological aspect of mental activity (regarding the involvement of cortical locus) is the level of local cerebral activation. For this, event related desynchronization (ERD) (with a reduction of wave amplitude) is the most popular and important EEG indicator. Event related synchronization, as a rule, is considered as expressing local inactivation (Pfurtscheller et al., 1988; Pfurtscheller, 1992). The classical phenomenon of α-desynchronization in the occipital areas, the most obvious expression of activation, has proved also to be a quite sensitive indicator of the higher functional state of other cortical regions (particularly during relatively short epochs). β-desynchronization has also shown similar functional correlates (Petsche et al., 1988; Pfurtscheller et al., 1988; Davidson et al., 1990; Burgess and Gruzelier, 1993; Fernandez et al., 1995). Such inhibitory and functionally 'negative' interpretation of a synchronized EEG rhythm is in accordance with the traditional neurophysiological notion which considers the wave amplitude as a function of number of neuronal elements and pools with synchronous electrical activity (Elul, 1971). The more elements are synchronized, the less their activity is differentiated and thus their capacity for information processing is reduced (Darrow, 1947; Klingberg, 1971, 1977; Bekhtereva and Bundzen, 1974; Iznak, 1989).

However, activation is not exclusively connected with EEG desynchronization; similarly, a rhythm's amplitude synchronization is not always a reflection of inactivation. For example, in many cases of mental effort, the α-desynchronization is accompanied by increase of β-activity (Matousek et al., 1969; Giannitrapani, 1971; Carter et al., 1986; Kakizaki, 1987; Petsche et al., 1988). Moreover, an increase of wave synchronization has also been observed during mental activity in lower frequency bands and even in α. Very often this occurs in those cortical areas which relate to the key elements in the neuropsychological concept of cortical organization of the mental functions studied. Examples are the κ-rhythm (pertaining to the α-frequency band) in temporal areas during mental activity based on verbal processes (Kennedy et al., 1948; Glanzer et al., 1964), or frontal θ-rhythm and Δ-waves which correlate with mental effort. They are considered as related to 'internal concentration' and presumably reflect the operational aspect of intellectual activity and intellectual attention (Ishihara and Yoshii, 1972; Gille et al., 1979; Gundel and Wilson, 1992; Bruneau et al., 1993; Fernandez et al., 1995). These cases of EEG synchronization, in spite of their neurophysiological inhibitory significance, apparently cannot be directly treated as a sign of regional inactivation, since this would be at variance with behavioural and psychological criteria (Luria, 1966; Milner and Petrides, 1985) as well as with physiological data about intensification of

regional blood flow and metabolism in frontal areas during mental activity (Roland, 1985; Ingvar, 1987). This seeming contradiction can be explained by the hypothesis that the inhibitory nature of certain EEG rhythm, in addition to its 'negative' role in local inactivation, has a very important 'positive' regulatory modulating function which relates to different types of selectivity in mental processes (Sokolov, 1963; Giannitrapani, 1971; Nunn and Osselton, 1974). Rhythmical activity can enable the participation of some neuronal elements in the functioning of certain networks or functional systems, and inhibit their involvement in the irrelevant connections. This can be seen, for example, in interregional or local coherent connections, which have very important functional significance even at the low-amplitude level (Livanov, 1977; John and Schwartz, 1978; Petsche et al., 1993). It is important that the EEG rhythm maintains its modulatory function even at a low amplitude (Klingberg, 1971). Usually such 'low-amplitude EEG' modes of the brain's functioning accompany processes of mental selectivity and reflect cerebral activation. This is well known for basic models of selective processes such as Pavlovian 'internal inhibition', which can be carried out at high levels of behavioural activity and actually demand higher functional states of the brain (Pavlov, 1951; Livanov, 1977; Gassanov, 1988).

So, in the study of 'low-amplitude EEG' modes during mental activity, there is an evident requirement to evaluate additional parameters of EEG rhythms (such as frequency) independently of the waves' amplitudes. It is known that fluctuations of amplitude synchronization (at least in the α-band) are substantially determined by fluctuations in the level of arousal related to comparatively 'non-specific' aspects of mental processes, such as the orienting reaction, habituation (which provides one of the most general and 'simple' forms of behavioural selectivity) and mental efforts dependent on the subjective difficulty of a task (Sokolov, 1963; Glanzer et al., 1964; Glass, 1967). Psychophysiological search for more task-specific EEG manifestations must consider different forms of mental selectivity. The rhythmical bioelectrical processes with their inhibitory function may be behind such selectivity. In the evaluation and physiological interpretation of the EEG changes during mental activity, the ERD approach (based on evaluation of spectral power) predominantly takes into account the 'inactivation' aspect of wave synchronization. This may be adequate in relatively short epochs of several seconds (which this method really deals with) when desynchronization is dominant. During prolonged epochs in neuropsychological testing (especially when certain types of mental tasks are repeated several times), an adaptation to the task is accompanied by habituation and partial restoration of the initial level of synchronization. In such conditions, it is supposed that some optimization of neuronal organization in mental operations takes place (Khomskaya, 1972; Pavlova, 1979). In previous work (Lazarev, 1989), it was shown that a repetition of similar tasks could provide substantial accentuation of task-specific EEG patterns (based on techniques described below), which were not revealed in the first performance of such tasks. In these cases, an evaluation of the functional significance of certain EEG rhythms during mental activity apparently cannot be restricted to the use of desynchronization as a measure of activation. It evidently should take into account both 'inactivation' and 'selective' aspects of the rhythmic activity, which relate to different and maybe independent 'dimensions' of a local functional state. The average spectral characteristics of a broad frequency band predominantly reflect an influence of high-amplitude synchronized segments of the long EEG epochs and the low-amplitude desynchronized ones (frequently more important in mental activity, since they relate to high levels of cerebral activation) may be totally obscured.

The difference in functional significance of the presence of the waves of certain frequencies and their level of amplitude synchronization has been noted since the beginning of the EEG. In the practice of conventional EEG analysis, it found expression in the traditional separation of the index of the waves of a given band (their prevalence expressed as percentage of presence in

epoch) and their amplitude (Davis, 1941). Spectral power, particularly when calculated over long epochs, is determined by a combination of both amplitude of the waves and their index. However, conventional EEG shows that variations of these two parameters can be quite poorly correlated: an increase of the index may be accompanied by a decrease in the amplitude and vice versa (Legewie et al., 1969) with little change in the spectrum. Under certain experimental and clinical conditions, a separation of the index and amplitude can thus provide additional information compared to spectral analysis (Nebylitsyn, 1963; Glaria and Murray, 1985; Lorig, 1986; Lazarev, 1992). It may be obtained by manual methods (Vogel et al., 1968; Legewie et al., 1969) or by more advanced automatic or computerized techniques (Zhirmunskaya et al., 1977; Monakhov et al., 1979; Itil et al., 1985, 1991; Iznak and Chayanov, 1989).

Based on the above considerations, both the amplitude and frequency index variation in the different types of EEG reactions during mental activity should be systematized. The traditional broad-band spectral characteristics, for all their merits, sometimes give quite discrepant results, especially regarding non-homogeneity of local cerebral activation in prolonged epochs. This may well be an effect of the combination of functionally different EEG indicators (such as index and amplitude). This could confound the powerful processes of synchronization/desynchronization with finer task-dependent changes in EEG.

The present research attempts to resolve a part of these problems by means of period (interval-amplitude) and factor analyses. Initially, this is done within the limits of the four standard broad frequency bands [although their functional validity can be questioned (Basar, 1980)]; this provides a rather general characterization of the data and enables us to concentrate on the problem of intercorrelations between amplitude and frequency parameters of EEG in psychophysiological paradigms. Period analysis evaluates the average period (in each epoch) of the EEG waves in each band independently of their amplitude (provided they exceed a selected amplitude threshold) and separates the amplitude and index. Factor analysis determines groups of EEG parameters which are intercorrelated (and therefore presumably functionally related) and combines them into the independent EEG factors. In this way, it compresses the information into a compact description by several integral characteristics that, one may expect, are functionally significant. Such compact data presentation provides more stable results which are less subject to random effects facilitating the interpretation of results (Nebylitsyn, 1963; Überla, 1977; Bochkarev and Nikiforov, 1981). This enables us to reveal and quantitatively evaluate via EEG factors a set of integral cerebral mechanisms which cause the observed correlated variations of primary EEG parameters and presumably relate to qualitatively different neurophysiological processes forming the complex multidimensional neurodynamic structure of the functional state in each locus of the brain. The present research is aimed at the psychophysiological interpretation of these processes through variations of values of the principal EEG factors in a broad range of functional states which are simulated by neuropsychological tests (intellectual, perceptive and motor) in normal subjects. In particular, we search for additional 'measurements' of cerebral functional state, beyond the synchronization aspect of bioelectrical waves, which could reflect more detailed independent task-specific changes in EEG.

In addition, such results should also demonstrate interrelations between amplitude and frequency and help to elucidate the methodological problems. In which bands (if any) do the traditional broad-band spectral characteristics averaged over long epochs combine functionally different primary parameters (such as the index and amplitude) and which combinations are more suitable to evaluate different 'physiological factors' in psychophysiological experiments?

2. Method

2.1. Psychological testing procedure

The volunteers were 42 males and 53 females,

students and employees of the university and research institutes in Moscow. None had a history of neurological, psychiatric, or drug-related illness. They were between 18 and 40 years of age with a median age of 23.7. None was overtly left-handed (according to the reports of the subjects and their writing hand).

They were divided into three groups according to the tests to be performed. Organization of the testing followed the above-stated 'contrast' principle. Thirty-four subjects in the first group performed two types of intellectual activity only. Another 34 subjects in the second group performed both 'perceptive' and 'intellectual' tasks, and 27 subjects of the third group performed only rhythmical motor tasks.

The intellectual activity consisted in the silent performance of associative verbal tasks [during 1 min, matching as many as possible rhymes to the given Russian noun like день (day) with the possible rhymes тень (shade), пень (stump), олень (deer), etc.] and mental arithmetic tasks (multiplying two-digit figures like 14×17, 13×28, 23×27, 24×32, etc.). In the first and second groups, the tasks were the same and were presented to the subjects orally. A 'contrast' of these two types of intellectual activity consisted in the relative predominance of successive (verbal associations) or simultaneous (mental arithmetic) operations (Luria, 1966) and in different levels of verbalization (interhemispheric differences). It also concerned subjective difficulty, habitualness and automation of mental operations (see Sec. 4). Both kinds of tasks were performed five–seven times each. They were interchanged in order to eliminate fluctuations in the level of vigilance (Makeig and Inlow, 1993). An EEG epoch (26-s duration) was registered 5 s after the beginning of each performance. Only the tasks with correct results were taken into account.

The perceptive activity consisted in analysis of a continuous series of tones of short duration (1.0 s, 60 dB) at five different pitches (250–5000 Hz) alternating randomly at intervals of 0.3 s. The subjects were instructed to pick out and count the tones of a certain pitch 1.5 min after turning on the sounds. One EEG epoch (20-s duration) was registered 20 s after the beginning of counting (in order to eliminate any orienting reaction). The results of tasks were checked. In the second group, the EEG data in non-verbal 'external' (environmental) (Ray and Cole, 1985) perceptive activity were considered in contrast with those of the 'internal' intellectual mental operations based on verbal processes.

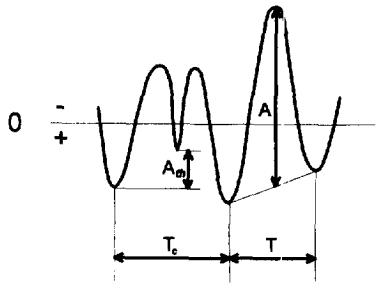
The 'contrast' of the motor tasks concerned contralateral topography of sensorimotor projections. The tasks consisted of rhythmical clenching of one fist for 1 min (approx. 1 clench per second) which was compared to the following similar movements of the other fist. This sequence of tasks was repeated. The order of the hands was randomly decided. In each performance, the EEG epoch (26-s duration) was registered 20 s after the beginning of movement of either hand.

Several (five–seven) 'background' EEG epochs (20-s or 26-s duration) during relaxed wakefulness were recorded before psychologic testing. The eyes were closed throughout the experiment (with monitoring of closure oriented to eye movements).

2.2. Primary EEG analysis

Recording of the EEG by the Nihon Kohden machine was monopolar at four or eight symmetrical scalp points of both hemispheres, viz. in the central (C3, C4) and parietal (P3, P4) regions or, in addition, in the frontal (F3, F4) and occipital (O1, O2) areas according to the International 10/20 System, with unilateral references to corresponding earlobes. The recording characteristics were: 0.3-s time constant, 30-Hz high-frequency filter and 10-μV/mm sensitivity. The digital sampling frequency was 200 Hz.

The computerized period (interval-amplitude) analogue of conventional EEG analysis was used. It was developed by A.I. Nikiforov and V.K. Bochkarev. This method has demonstrated substantial resolving power in differentiating endogenous mental diseases and pathological functional states during therapy (Nikiforov and Bochkarev, 1974; Monakhov et al., 1979, 1983; Bochkarev and Nikiforov, 1981 Nikiforov, 1981; Lazarev, 1986a; Bochkarev et al., 1987). The anal-



T - period
A - amplitude
T_c - period of compound wave
A_m - amplitude threshold for compound wave

Fig. 1. Diagram of general principles of EEG period analysis.

ysis presented here is based on the evaluation of the period of a bioelectrical wave between two adjacent positive peaks. The amplitude of a wave could be defined as the distance (orthogonal to the isoelectrical line) between the negative peak and the line connecting the two adjacent positive peaks (Fig. 1) (Nikiforov and Bochkarev, 1974; Brain Scan System, 1991). Only the waves exceeding the threshold of 5 μV were taken into account. This threshold was selected because it was higher than the noise level and more effective in distinguishing functional and clinical states than were the thresholds of 8 and 10 μV. Compound waves that included simple oscillations of smaller periods were taken into account if both the positive peaks of a compound wave exceeded those of simple waves (included in the compound wave) by more than 15 μV (Fig. 1).

This analysis provides a detailed description of a local EEG process in each lead by a set of the following four primary parameters in four standard frequency bands: (1) index of the waves of each band (independently of the coexisting waves of another bands) defined as a temporal percentage of their presence in the epoch; (2) average (in epoch) period of all the waves of each band; (3) average wave amplitude; and (4) regularity, as the mean number of the waves of the same band following each other in succession (averaged over all the fragments with such a succession).

All the parameters were averaged in 20-s or 26-s EEG epochs free of ocular artifacts (according to visual control). The EEG bands were defined as follows: Δ, between 1.0 and 3.5 Hz; θ, 3.5–7.5 Hz; α, 7.5–12.5 Hz; and β, 12.5–30.0 Hz.

2.3. Secondary EEG data processing

In each lead, the factor analysis with varimax rotation (Harman, 1967) was performed. It was based on the cross-correlation of the 14 aforesaid primary EEG parameters (the index, period, amplitude in all the bands and the regularity in α- and β-bands — units of dispersion) throughout their inter-individual variations in each group of subjects. The regularity of the θ- and Δ-waves was not taken into account since their values usually were close to 1.0 wave/fragment without expressed variation.

Before being subject to factor analysis, primary EEG data of several performances of each kind of task was averaged for each subject (except those of the first performances of both kinds of intellectual tasks which were analyzed separately). Only the factors with eigenvalues over 1.0 (7.14% of the total dispersion or variance) were taken into account.

A certain similarity of physiological mechanisms that form inter-individual EEG differences and affect the EEG changes related to various states of wakefulness (Zhirmunskaya and Makarova, 1975) was assumed. It means that the EEG factors revealed on the basis of inter-individual variations of the primary EEG parameters reflect some general neurophysiological mechanisms and processes common to the subjects of a group. These mechanisms can cause the EEG dynamics observed during psychological testing. Our previous results have shown that they really can be similar in different functional states of relaxed wakefulness and mental activity. This was reflected in similarity of structure of the principal EEG factors revealed during neuropsychological testing (Lazarev, 1985, 1986b, 1988, 1989) (see below). This enabled us to evaluate quantitative differences between functional states (simulated by testing) in the values of the same EEG factors. Such unified factors were obtained on the basis of primary EEG data averaged over all the functio-

nal states studied in the group (including background), or by variation of the primary parameters throughout the functional states in addition to the basic inter-individual variation. The latter means the following: in the ensemble of primary EEG data subject to factor analysis in all group, each subject was represented by several sets of 14 primary EEG parameters according to the number of states studied (three states in the first and third groups and four states in the second group), each state being treated as a new case. For the same reason and in the same way, the primary EEG data of different leads (where the structure of principal EEG factors was similar) were unified before factor analysis. In the first group, it was made by averaging the data of symmetrical points of different hemispheres, and in the second and third groups, the inter-individual variations of primary EEG parameters in four or three functional states were supplemented by variation throughout four EEG derivations. In our previous research, the structure of such unified factors did not differ significantly from that of the factors obtained in each functional state or derivation (Lazarev, 1986b, 1988, 1989).

Individual values of the unified EEG factors in each functional state were evaluated (Harman, 1967). In each group of subjects in each lead, all the functional states studied (including the background) were compared in these values averaged for all the group. In the third group, such comparison was also made between different leads in each state. Statistical significance of the differences was obtained by using Student's paired *t*-test, as only the difference between pairs of states was of interest.

Table 1
Structure of principal EEG factors in relaxed wakefulness ('background') in 95 subjects of all three groups

Numerical designition of factors	Primary EEG parameters	Points of recording								
		Fs	Fd	Cs	Cd	Ps	Pd	Os	Od	U
		Factor loadings × 100								
Ia	θa	69	91	—	—	—	—	—	—	—
	Δa	91	88	—	—	—	—	—	—	—
% dispersion		**16**	**20**	—	—	—	—	—	—	—
I	βa	64	—	80	85	77	82	85	78	85
	αi	77	65	81	88	91	87	78	87	86
	αa	82	70	95	96	95	95	87	94	94
	αr	67	—	61	72	81	70	60	87	76
	θi	—	—	—	−62	−69	−67	—	−62	−64
	θp	−75	−70	−70	−70	−80	−76	—	—	−68
	θa	—	—	83	87	85	87	87	80	80
	Δi	−86	−74	−79	−84	−87	−84	−70	−79	−81
	Δp	−78	−82	—	−67	—	—	−71	—	—
	Δa	—	—	—	—	—	75	—	64	—
% dispersion		**34**	**28**	**37**	**43**	**45**	**43**	**35**	**41**	**41**
II	βi	93	95	94	89	77	87	71	75	87
	βp	−82	−84	−82	−79	−72	−82	−85	−86	−82
	βr	91	88	83	84	89	90	90	87	88
% dispersion		**22**	**23**	**20**	**18**	**17**	**19**	**15**	**17**	**18**
III	αp	95	91	92	88	94	94	95	90	93
	θi	72	84	80	71	65	70	72	66	72
% dispersion		**13**	**17**	**16**	**14**	**14**	**14**	**14**	**16**	**14**

The highest ($>|0.6|$) factor loadings are presented.

Note. i, index; p, period; a, amplitude; and r, regularity of β-, α-, θ- and Δ-waves; F, frontal; C, central; P, parietal; and O, occipital points of left (s) and right (d) hemispheres; U, unified data based on both interindividual and interregional variation of the primary EEG parameters (see 'Secondary EEG data processing').

3. Results

3.1. Principal EEG factors

In different groups of normal subjects in different areas of EEG recording, a reasonably stable factor structure of the local EEG parameters was revealed in all the functional states studied. This structure consisted of three generalized (i.e. revealed in all the recorded areas) factors which comprised 60–76% of the total dispersion (variance) of primary EEG parameters (Tables 1 and 2; Figs. 2–4) and one regional factor of the anterior areas (10–21% of the total dispersion) (Tables 1 and 2; Fig. 2; in the cases of Figs. 3 and 4, the regional factor of similar structure exists as well but is not presented in the figures).

According to the data obtained, Factor I comprises the greatest variation in the primary EEG parameters (30–45% of their total dispersion). The index, amplitude and regularity of α-waves always had maximum positive factor loadings (0.60–0.96). The amplitude parameters of other bands also related to this factor by high positive factor loadings, higher in the parietal and occipital regions (0.60–0.92). The Δ- and θ-indices and their mean periods proved to be in reciprocal relation to the above-mentioned parameters. They had high negative factor loadings (-0.60 to -0.93, the Δ-index having highest negative loadings).

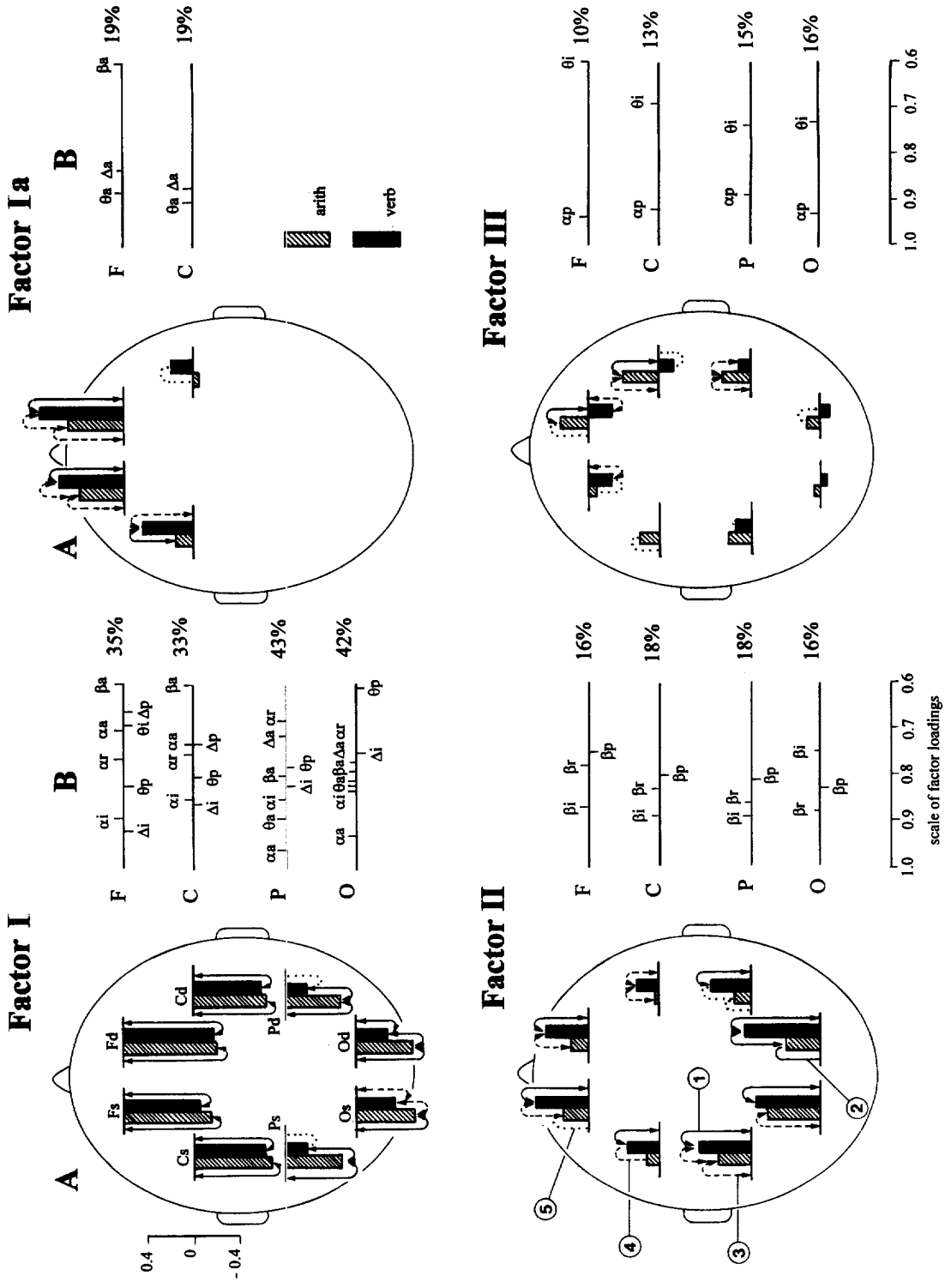
The amplitudes of slow waves related positively by high factor loadings (0.80–0.92) to separate Factor Ia (10–21% of the total dispersion) revealed in anterior regions. Sometimes its structure could also include α- and β-amplitudes (with lower positive factor loadings 0.5–0.6).

Factor II (15–23% of the total dispersion) re-

Table 2
Structure of principal EEG factors in intellectual activity in 34 subjects of the first group

Numerical designation of factors	Primary EEG parameters	Mental multiplication				Matching the rhymes				Both activities unified with the 'background'			
		Areas of recording											
		F	C	P	O	F	C	P	O	F	C	P	O
Ia	θa	92	90	—	—	90	89	—	—	88	90	—	—
	Δa	90	89	—	—	86	87	—	—	83	87	—	—
% dispersion		**21**	**19**	—	—	**21**	**20**	—	—	**19**	**19**	—	—
I	βa	61	60	63	73	60	—	79	79	60	60	80	81
	αi	95	89	65	70	94	85	78	71	89	85	85	82
	αa	69	73	88	90	65	67	95	87	70	73	96	93
	αr	86	83	64	77	81	73	54	59	77	75	68	77
	θi	−72	−67	—	—	−77	—	—	—	−70	—	—	—
	θp	−73	−72	−60	—	−76	−79	−77	−63	−82	−80	−78	−61
	θa	—	—	92	90	—	—	89	90	—	—	89	82
	Δi	−93	−88	−60	−60	−92	−89	−79	−67	−92	−86	−82	−75
	Δp	−60	−74	—	—	—	−76	—	—	−66	−73	—	—
	Δa	—	—	90	87	—	—	67	83	—	—	71	79
% dispersion		**35**	**35**	**32**	**36**	**34**	**31**	**39**	**36**	**35**	**33**	**43**	**42**
II	βi	91	86	84	79	92	92	91	84	87	89	89	75
	βp	−78	−82	−85	−78	−82	−80	−81	−78	−75	−80	−81	−83
	βr	84	84	85	88	86	86	87	89	78	83	86	88
% dispersion		**18**	**19**	**17**	**17**	**19**	**19**	**20**	**17**	**16**	**18**	**18**	**16**
III	αp	96	93	91	96	87	91	85	89	94	92	89	93
	θi	60	63	82	71	61	70	80	85	60	70	74	73
% dispersion		**09**	**13**	**21**	**16**	**09**	**13**	**16**	**21**	**10**	**13**	**15**	**16**

See Table 1 for key.


Factor I
A
Cs
Fs
Ps
Fd
Cd
Pd
Os
Od
0.4
0
-0.4
B
F
C
P
O
αi Δi αr αa θp θi Δp βa
αi Δi αr αa θp Δp βa
αa θa αi βa Δi θp Δa αr
αa αi θa βa Δa αr Δi θp βa
35%
33%
43%
42%
Factor Ia
A
B
F θa Δa βa 19%
C θa Δa 19%
arith
verb
Factor II
Factor III
F αp θi 10%
C αp θi 13%
P αp θi 15%
O αp θi 16%
F βi βr βp 16%
C βi βr βp 18%
P βi βr βp 18%
O βr βi βp 16%
1.0 0.9 0.8 0.7 0.6
scale of factor loadings
1
2
3
4
5

lated to all the parameters of β-activity except amplitude, viz. the index and regularity had positive factor loadings (0.70–0.92) and the mean period had negative loadings (−0.70 to −0.85).

In the structure of Factor III (9–21% of the total dispersion), the maximum positive factor loadings belonged to the mean α-period (0.80–0.96) and to the θ-index (0.60–0.90).

3.2. Dynamics of EEG factor values during intellectual and perceptive activity

Figs. 2 and 3 illustrate the diversely directed changes of different EEG factor values during intellectual and perceptive activity as compared with those of relaxed wakefulness — background (zero line). Every type of activity was accompanied by a characteristic decrease of Factor I values. Such a reaction was most pronounced during arithmetic and perceptive activity ($P <$ 0.02–0.001 in different points of recording), whereas reaction to verbal tasks was fainter ($P <$ 0.1–0.001 in regard to the background; $P <$ 0.05–0.001 in regard to the other tasks).

The differences between verbal and arithmetic tasks in Factor I values had a topographically expressed aspect. It consisted in almost equal or close reaction during both types of intellectual activity (in comparison to the background) in the fronto–central regions as opposed to the significantly higher reduction in Factor I values in the parieto–occipital regions during mental multiplication ($P < 0.02$–0.001 in regard to verbal activity) (Fig. 2).

On the contrary, the 'anterior' Factor Ia values increased during intellectual activity. This was more expressed during performance of the verbal tasks when this reaction prevailed in the frontal and left central areas ($P < 0.02$–0.001 in regard to the background; $P < 0.02$–0.001 in regard to mental arithmetic) (Fig. 2).

Factor II values increased in both types of intellectual activity. But this reaction was greater when matching rhymes ($P < 0.05$–0.001) than during mental arithmetic ($P < 0.1$–0.001), so that Factor II values in the former were higher than those of the latter ($P < 0.1$–0.001) (Figs. 2 and 3). Meanwhile, the counting of the tones was accompanied by a reciprocal (as compared with intellectual activity) decrease in Factor II values ($P <$ 0.1–0.05 in the parietal areas). It resulted in significant predominance of Factor II values in intellectual activity over those of perceptive activity ($P < 0.1$–0.001) (Fig. 3).

An increase of Factor III values was characteristic of mental arithmetic, and it was most pronounced in the right hemisphere ($P <$ 0.1–0.02) (Figs. 3 and 4). The verbal activity was not accompanied by clear shift of Factor III values (Figs. 2 and 3), this reaction was quite faint. Its direction could be positive ($P < 0.05$) in the left central region (Fig. 3) or even negative ($P <$ 0.02) in frontal regions (Fig. 2). Nevertheless, there was a clear trend of Factor III values' predominance during mental arithmetic over those of verbal activity. These differences were predominantly expressed in the right hemisphere ($P < 0.1$–0.001) (Figs. 2 and 3).

Reaction of increase of Factor III values during perceptive activity was quite faint ($P < 0.1$–0.05 in central regions) (Fig. 3). Nevertheless, the changes of Factors II and III values during this

Fig. 2. Dynamics of values of principal EEG factors in intellectual activity (in the first group of 34 subjects). (A) Bar-graphs of changes of the group averages of the different EEG factor values during matching rhymes (verb) and mental multiplication (arith) in comparison with background (state of relaxed wakefulness — zero line), increase — upwards from the line, decrease — downwards, in frontal (F), central (C), parietal (P) and occipital (O) areas of the left (s) and right (d) hemispheres. The values are normalized by their standard deviation (units of dispersion). Arches between bars and to zero line indicate level of statistical significance of differences in EEG factor values between the three functional states: (1) solid line — with arrows, $P < 0.001$; (2) solid line — no arrows, $P < 0.01$; (3) dashed line — with arrows, $P < 0.02$; (4) dashed line — no arrows, $P < 0.05$; and (5) dotted line, $P < 0.1$ (see Factor II). (B) Structure of EEG factors in different areas of the brain (F, C, P, O) as given by the primary EEG parameters (i, index; a, amplitude; p, period; and r, regularity of α-, β-, θ- and Δ-waves) and their factor loadings. The scale is given at the bottom of the graphs. Above axis — positive loadings, below — negative loadings. On the right of the axes percentage of the total dispersion of primary EEG parameters explained by EEG factors.

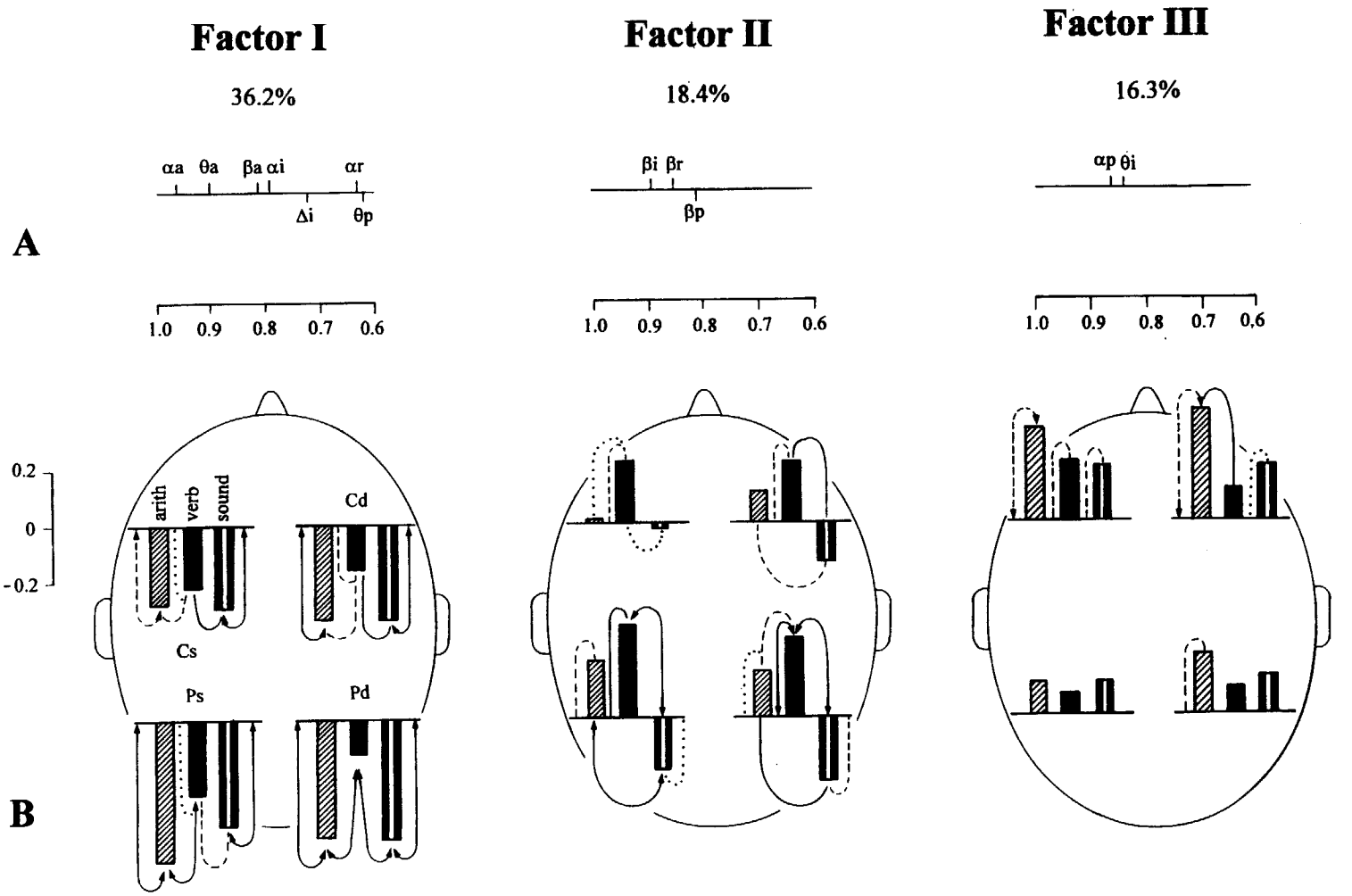


Fig. 3. Comparative dynamics of values of three generalized EEG factors in intellectual and perceptive activity (in the second group of 34 subjects). (A) Structure of EEG factors, percentage of the total dispersion being plotted over axes (see Fig. 2B). (B) Bar-graphs of changes of EEG factor average values during matching rhymes, mental multiplication and analyzing of sound stimuli (sound) in comparison with background (zero line) (see Fig. 2A).

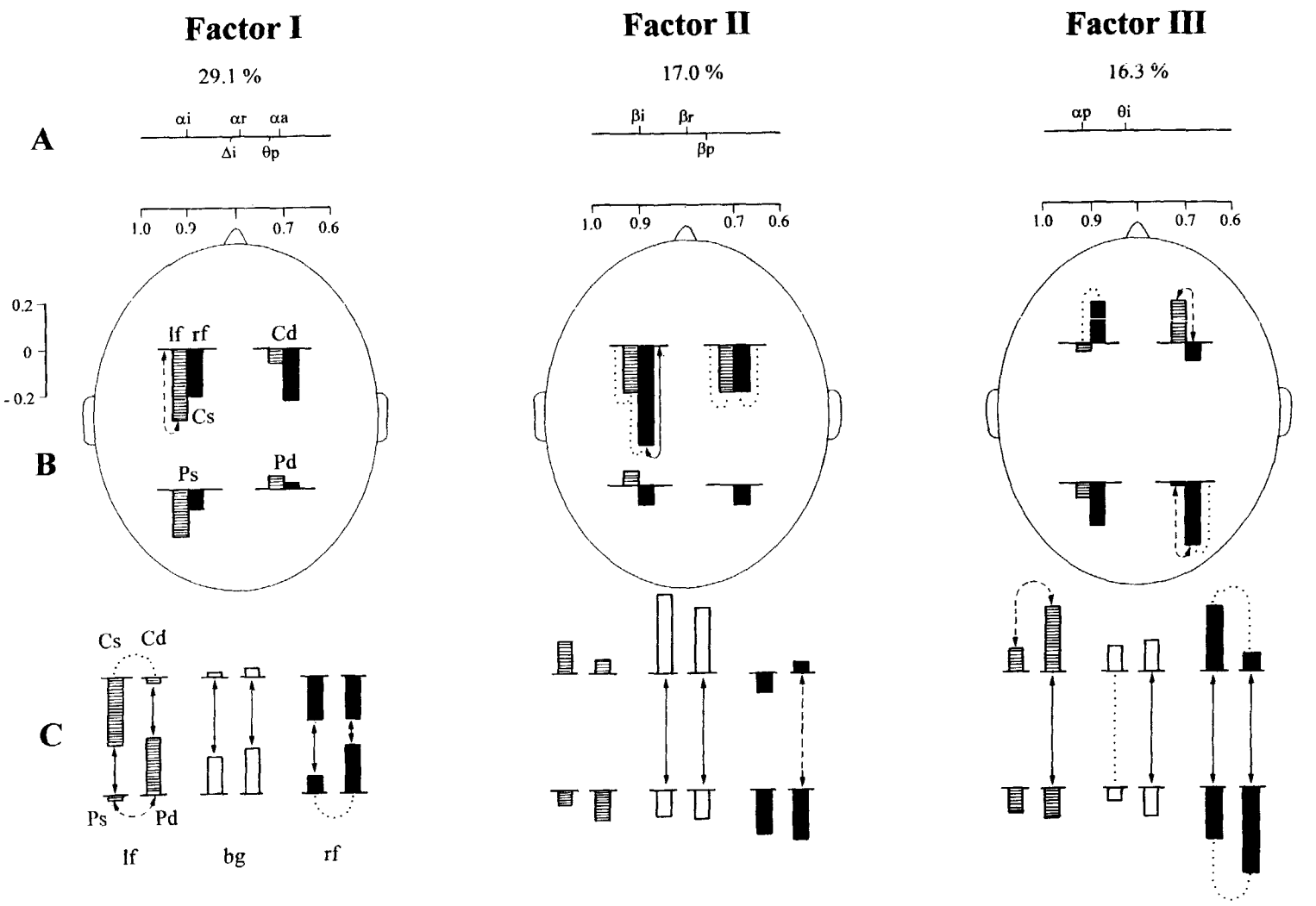


Fig. 4. Dynamics of values of three generalized EEG factors in motor activity (in the third group of 27 subjects). (A) Structure of EEG factors (see Fig. 2B and Fig. 3A). (B) Bar-graphs of changes of EEG factor average values during clenching of left (lf) and right (rf) fists in comparison with background (zero line) (see Fig. 2A). (C) Topographic distribution of EEG factor average values among four brain regions (Cs, Cd, Ps and Pd) in clenching of left and right fists and in background (bg). The arches, lines and arrows indicate level of statistical significance of inter-regional differences in EEG factor values (see Fig. 2A).

'external' type of mental activity were found to be reciprocal, i.e. contrary-directed owing to the above-mentioned decrease of Factor II values. This contrasted to the foregoing dynamics of the values of these factors during 'internal' intellectual activity (particularly mental arithmetic) when they changed in the same direction of augmentation.

The differences in the values of Factors II and III between verbal and arithmetic tasks were seen in subsequent (second, third, *etc.*) performances. But there were no significant differences between these two types of intellectual activity when performed for the first time.

3.3. Dynamics of EEG factor values during motor activity

Changes of EEG factor values during motor activity are illustrated in Fig. 4. Factor I values decreased only in the left hemisphere when the subject's left hand was working ($P < 0.02$ in the left central region) (Fig. 4B). It resulted in the marked shift of interhemispheric asymmetry towards the greater right side prevalence of Factor I values ($P < 0.1$ in the central and $P < 0.02$ in the parietal areas) (Fig. 4C).

Factors II and III values moderately changed in contrary directions (similar to the afore-cited reaction during perceptive activity), viz. Factor III values increased, whereas Factor II values decreased ($P < 0.1$–0.001), such reciprocity taking place only in contralateral (regarding the subject's moving hand) central region (Fig. 4B). This unilateral increase of Factor III values was accompanied by their decrease in opposite central and in both parietal regions ($P < 0.1$–0.02 for the differences between the movements of subjects' different hands) as well as by the decrease of Factor II values all over the recorded scalp points ($P < 0.1$) especially in the left central region during clenching of the subject's right fist ($P < 0.001$) (Fig. 4B). Such topographic distribution of the reactions resulted in significant interchange of contrary interhemispheric asymmetry in the central regions depending on the laterality of the subject's working hand. In the main, it concerned Factor III ($P < 0.1$–0.02) but Factor II values had a similar trend as well (Fig. 4C).

4. Discussion

Stability of the obtained factor structure of the period EEG parameters (in different groups, different types of mental activity and different scalp points) accords with our previous results. In the study of more than 60 combinations of normal subjects and psychiatric patients with borderline endogenous symptomatology, this structure proved to be similar and did not much depend on age and sex, on functional state of wakefulness (16 states were studied), or on scalp point of EEG recording (in the latter case, only the afore-cited regional Factor Ia differentiated the anterior areas from the other regions) (Lazarev, 1985, 1986a,b, 1988, 1989, 1992; Bochkarev et al., 1987). This may well be indicative of the relative universality of independent neurophysiological mechanisms and processes which lie behind the revealed EEG factors (in the sense that they act in different conditions of the awake cerebral functioning). These processes evidently coexist in any cortical area and cause intercorrelation in certain groups of primary period EEG parameters throughout their inter-individual variations as well as through their changes in different functional states. These mechanisms evidently form a multidimensional 'neurodynamic structure' of the functional state of each brain locus by certain balance of independent neurophysiological processes which is peculiar to certain types of mental activity in accordance with their neuropsychological organization. Such a balance can be quantitatively evaluated by the values of different EEG factors.

Certain functional attributions of the EEG factors can be made on the basis of known properties of the primary EEG parameters (which relate to each factor's structure by high factor loadings), as well as on the strength of characteristic dynamics of the values of EEG factors during psychological testing when the general direction of the change from relaxed wakefulness to mental activity can be treated as a criterion of 'higher functional state'. From this point of view, the

structure of the revealed EEG factors does seem to be quite naturally determined.

According to the structure of Factor I, a decrease of its values during almost all the types of mental activity studied means the following changes of the primary EEG parameters: a simultaneous decrease of the index, mean amplitude and regularity of the α-waves as well as of the wave amplitudes in other bands, and an increase (in parallel) of the indices and mean wave periods in the Δ- and θ-bands. These changes include as main part a reaction of EEG desynchronization which is well known as the most obvious expression of the brain's 'general activation' (see above). In this reaction, the values of Factor I decreased in proportion to difficulty and novelty of tasks and stimuli. More pronounced reaction was observed during performance of arithmetic tasks which were subjectively more difficult in comparison with verbal ones (according to the subjects' reports), as well as during the first performance of the verbal tasks as compared with the ones which followed (Lazarev, 1989), and during movements of the subject's left hand (more unaccustomed in right-handers) as compared with those of the right hand. The same dependence upon difficulty and novelty was also revealed in our previous research of sound stimuli perception (Lazarev, 1988). In that work, the dynamics of Factor I values developed from pronounced reduction in orienting reaction (when unexpected sounds drew subject's involuntary attention) through return towards almost the initial background level in a state of 'habituation' (when stimulation was repeated many times) and to a recurring reduction during analysis of sound stimuli similar to that of the present research (when voluntary attention was involved), the extent of such a decrease of Factor I values being dependent on the varied task difficulty.

In spite of the relative 'non-specificity' of reactions in Factor I values in general, some additional task-dependent features of 'general activation' can be revealed in its topographical display. A direct comparison of two contrasting intellectual tests in each point of recording enabled us to abstract from a general level of activation (which was higher in more difficult arithmetic tasks). This revealed comparatively higher activation of parieto–occipital areas (where differences between two kinds of tasks were maximal) during mental multiplication, and of fronto–central areas (where the above-mentioned differences were minimal) and the left hemisphere during verbal associations. A shift of interhemispheric asymmetry of Factor I values towards more marked right-sided prevalence (which implied a left-sided prevalence in EEG desynchronization) during both kinds of intellectual activity, verbal tasks being more effective in such a reaction, was observed in our previous special topographical investigation with the same intellectual tasks (Lazarev, 1987). Similar patterns of regional activation during the same types of mental activity were also obtained in our former research based on multichannel mapping of distance synchronization of biopotentials (Lazarev et al., 1977a) and EEG spectral power mapping (Lazarev, 1992). These patterns are in accordance with neuropsychological notions concerning the particular active role of the parieto–occipital associative regions in mental calculation owing to simultaneous spatial and quasi-spatial types of syntheses (Hecaen et al., 1961; Luria, 1966); and of the fronto–centro–temporal areas and left hemisphere in successively organized and verbalized processes including verbally mediated active voluntary attention (Luria, 1966; Butler and Glass, 1974; Gordon and Bogen, 1974; Khomskaya, 1980). Perhaps owing to verbalization of voluntary attention, a left-side shift in regional activation was observed during not only matching the rhymes and (to a lesser degree) in mental multiplication but even during working of the subject's left hand. Such asymmetry in motor activity (in spite of the expected contralateral effect) is probably due to more pronounced influence of voluntary control because of relative 'unaccustomedness' of the left hand working in right-handers. It was also observed in activation patterns obtained earlier by distance synchronization of biopotentials multichannel mapping (Lazarev, 1978).

According to Factor II structure, an increase of its values during mental activity relates to an increase of the index, frequency and regularity of the low-amplitude β-waves, the β-amplitudes

usually being desynchronized at the same time together with the above-mentioned decrease of Factor I values. Other authors observed certain inverse changes of the number of β-waves and their amplitudes during mental activity (Legewie et al., 1969) as well as a positive correlation of the β amplitude with amplitudes of the α- and θ-waves (Nebylitsyn, 1963; Rusinov et al., 1987). Factor II can apparently be considered as a reflection of some 'cortical excitation' processes which are traditionally connected with β-activity abundance.

Factor III values increased during mental activity too. This reaction means an increase of θ-index (θ-amplitude usually decreased in parallel together with Factor I values, except in the anterior areas where it increased together with Factor Ia values) and of the α-waves' mean period. Such combination is in accordance with the concept regarding functional similarity of the θ- and slow α-waves (Mundy-Castle, 1957; Schacter, 1977; Klimesch et al., 1994). Some modern methodological approaches offer to combine these frequencies into a common band (Etevenon et al., 1982; Pfurtscheller et al., 1988). Concerted augmentation of θ-activity and deceleration of the α-waves were observed by other authors (Vogel et al., 1968; Gale et al., 1975).

Thus, the obtained dynamics of Factor III values during mental activity means certain effects of the wave deceleration (independent of the wave amplitudes) in the middle part of the range of EEG frequency bands. In accordance with general neurophysiological notions, such deceleration must be a reflection of certain inhibitory processes. But this inhibition intensified in the 'higher' functional states of mental activity when an expressed increase of 'general activation' was indicated by a decrease of Factor I values. During motor activity, such inhibition was localized in the most involved sensorimotor projection areas contralateral to the subject's working hand. All this implies that these types of inhibitory processes are obviously 'active' by nature. Similar reactions during mental activity were earlier registered separately in the $\Delta-\theta$ and α-bands (Vogel et al., 1968. They were considered as a 'second class inhibition' of active wakefulness which provides a 'selectivity' of higher mental functions by inactivation of irrelevant connections within an activated system. This concept was shared by other authors (Schacter, 1977).

Traditional investigations in the physiology of higher nervous activity in animals and men demonstrated certain correlations between different types of Pavlovian 'internal inhibition' (including some complex forms of conditioned differentiation as one of the basic physiological components of mental selectivity) and a slowing of EEG rhythms (by both augmentation of slow waves and deceleration of the dominating rhythm's frequency) (Galeano et al., 1964; Kratin, 1967). The latter was proposed to be one of the obstacles or modulators in the way of diffusion of excitation in the cortex on both macro- and micro-level of the organization of cerebral processes (Livanov, 1977; Gassanov, 1988). This enables us to consider an increase of Factor III values as a reflection of some 'active selective inhibitory' processes. They are probably akin to the complex forms of 'internal inhibition' which demands higher levels of arousal and a higher strain of nervous processes (Pavlov, 1951; Gassanov, 1988). Such an interpretation was indirectly confirmed by the positive relation of Factor III to the sensory (auditory) sensitivity of different individuals (Lebedeva and Lazarev, 1989) since such sensitivity, in its turn, positively relates to the individual manifestation of different forms of 'internal inhibition' (Nebylitsyn, 1966; Ratanova, 1983).

More detailed functional properties of Factors II and III can be revealed on the basis of their values' prevalence in contrast tasks according to the tasks' psychological features that differentiate them. Thus, significant prevalence of Factor II values during matching rhymes over those of mental multiplication suggests a certain connection of 'cortical excitation' with the neurophysiological basis of successively organized associative mental operations which are peculiar to verbal processes. They must prevail during associative verbal tasks in contrast to mental arithmetic when simultaneously organized operations usually predominate (Luria, 1966). On the other hand, a general increase of Factor II values was characteristic of both types of 'internal' intellectual ac-

tivity (obviously verbally mediated), whereas their decrease was observed during analysis of non-verbal 'external' sound stimuli, both kinds of reaction taking place against a background of similar level of 'general activation' indicated by Factor I values. Reciprocal reduction of β-activity in 'external' perception (Gale et al., 1975; Etevenon et al., 1985) and augmentation during 'internal' attention is known in literature (Mundy-Castle, 1957; Matousek et al., 1969; Ray and Cole, 1985; Fernandez et al., 1995) (although the literature data regarding the dynamics of the β-spectral power during mental activity is very discrepant, perhaps because of the relation of β-amplitude and β-index to different independent EEG factors). In the present research, the psychological contrast between the 'external' and 'internal' cognitive tasks used suggests a certain relation of 'cortical excitation' to some verbally mediated processes involving search for memory traces. Such processes must be much more loaded during intellectual activity than during the perception of sounds. Perhaps they are based on some kind of 'local scanning' which has been ascribed to β-activity in some papers (Giannitrapani, 1971; Petsche et al., 1988). It is not unreasonable to assume either some correlation of 'cortical excitation' with certain aspects of creative productivity that differentiates matching rhythms from relatively more reproductive arithmetical calculation. It is known that β-activity is strengthened during the solution of new problems and is weakened during habituation, after decision of the problem or automation of mental actions (Sokolov, 1963).

In 'internal' purposeful intellectual activity, the afore-noted associative mental operations (presumably related to augmentation of Factor II values) need to be accompanied by a coexisting selection of relevant associations and inhibition of irrelevant ones; in perceptive and motor activity, some selective inhibitory neuronal processes are proposed be of a relatively 'purer' display without significant active involvement of the searching processes of memory associations. In all these cases, certain types of selectivity are probably related to Factor III. Comparative analysis of the cases of significant prevalence in Factor III values of one of the contrast tasks over another reveals at least three types of mental selective processes that may well be ascribed to this factor: voluntary attention, simultaneous organization of mental operations and automation of mental operations.

Voluntary attention is the most obvious selective process in both intellectual and perceptive kinds of cognitive activity.

Simultaneous mental operations establish the difference between mental arithmetic and successively organized verbal associations. They predominantly include different types of spatial and quasi-spatial syntheses (Hecaen et al., 1961; Luria, 1966). Simultaneous organization is more peculiar to processes in the right hemisphere (Gordon and Bogen, 1974; Khomskaya, 1980; Kostelianets et al., 1988) where the processes of 'lateral inhibition' are more pronounced than in the left hemisphere (Nevskaya et al., 1989). This may explain the obtained localization of predominance of 'active selective inhibition' (via Factor III values) during mental multiplication over that of verbal associations in the right hemisphere. The right-side prevalence in EEG α-deceleration during multiplication was observed in other papers by other methods of EEG analysis (Giannitrapani, 1969; Lazarev, 1992). Although mental arithmetic is a verbally mediated activity which activates the left hemisphere (Lazarev, 1992; Inouye et al., 1993), there are data about the very important role of the right hemisphere in the realization of calculations (Dimond and Beaumont, 1972; Simernitskaya et al., 1978; Qureshi and Dimond, 1979; Giannitrapani, 1982). Our other investigations have also shown higher activation of the right hemisphere in mental arithmetic as compared to verbal associations (Lazarev, 1987, 1992).

Simultaneous organization of mental operations can sometimes be connected with mental automation as a result of reiteration of some fixed succession of actions. This is a very important aspect of selectivity. It apparently optimizes neuronal organization of behaviour and mental processes. The afore-cited effects of increase of the slow waves' index together with α-deceleration during mental arithmetic (Vogel et al., 1968) (similar to the dynamics of Factor III values in the present research) were treated by authors as a

phenomenon presumably related to mental automation. Indeed, arithmetical tasks, despite their greater subjective difficulty, nevertheless require the performance of standard 'over-practiced' arithmetical actions and operations, committed to memory, with active exclusion of random associations. There are, therefore, reasons to suppose that these activities can be regarded as comparatively more automatized than verbal associations. In the same way, an increase of Factor III values in the projection sensorimotor areas during motor activity can be evidently ascribed to the effect of automation of reiterative rhythmic movements with local display of selective inhibitory neurodynamics of their optimized neuronal organization.

It is possible that the above-stated selective inhibitory processes contribute to the somewhat exceptional ability of θ-activity in the differentiation of cognitive tasks that is ascribed to this frequency by some authors (Legewie et al., 1969), particularly in regard to the operational side of intellectual strain (Gille et al., 1979). In the same way, in accordance with the dynamics of Factor III values, an intensification of visual cognitive processes can be accompanied by a slowing of α-activity (Gale et al., 1975; Zeller, 1986). In our previous research, α-deceleration during the same intellectual tasks was indirectly reflected by the redistribution of spectral power in the α-band (reduced as a whole) towards relative prevalence of the slow sub-band $\alpha 1$ (7.5–9.0 Hz). Such reaction during mental arithmetic prevailed over that of verbal associations, and this difference was expressed predominantly in the right hemisphere (Lazarev, 1992). Whether such a deceleration is a 'passive' result of more pronounced desynchronization of a 'specific' fast $\alpha 2$ component (9.5–12.5 Hz) (as it is assumed in afore-cited ERD approach) or whether it reflects some self-dependent 'active selective inhibitory' processes, largely depends on the interpretation of the functional role of the EEG rhythm and its amplitude parameters (see above).

It is interesting that in perceptive and motor tasks (when successively organized verbal associations and search for memory traces were not substantially loaded), the relatively 'purer' models of selectivity (such as focusing voluntary attention and motor automation) were accompanied by an inverse balance of intensified 'active selective inhibition' (increased values of Factor III) and reduced 'cortical excitation' (decreased values of Factor II). Moreover, during motor activity, this inverse effect displayed quite limited localization in the involved sensorimotor cortex and made for the opposite change of the interhemispheric asymmetry in both factors' values in accordance with laterality of the subject's moving hand. In a reiterative rhythmic motor task (quite similar to that of the present research) some attenuation of β-activity was also observed in motor areas with reaction prevalence contralateral to the moved hand (Burgess and Gruzelier, 1993). A negative correlation of β-activity with mental automation is quite well known (Darrow et al., 1957; Sokolov, 1963). On the other hand, the foregoing reciprocal dynamics of Factors II and III values are in accordance with the results of investigation of the individual 'automatization cognitive style'. This style was described as positively correlated with the number of slow waves and with α-deceleration and negatively correlated with the number of β-waves and their frequency (Vogel et al., 1968).

An increase of Factor Ia values in the anterior areas during intellectual activity reflects a general synchronization of the wave amplitudes predominantly in the slow frequency bands θ and Δ. As stated above, such type of frontal EEG reaction is described by many authors for all the broad bands: frontal θ-rhythm (Ishihara and Yoshii, 1972; Mizuki, 1987); Δ-activity (Etevenon, 1986; Kakizaki, 1987); β-activity (Petsche et al., 1988; Fernandez et al., 1995); and 'alphoid' rhythms of frontal areas (Mundy-Castle, 1957). The latter presumably are functionally close to κ-rhythm of temporal areas (Kennedy et al., 1948, Glanzer et al., 1964; Schacter, 1977) and usually correspond to a slower sub-band $\alpha 1$. In most of the afore-cited papers, an increase of the wave amplitudes in frontal and temporal areas was accompanied by their decrease in the same bands in all the post-central regions against a background of general activation indicated by desynchronization of the occipital α-rhythm. An augmentation of slow wave spectral power during mental activity was also accompanied by other activation indicators

such as an increase of distance synchronization of biopotentials and coherence of the Δ- and θ-activity (Sviderskaya, 1977).

When such frontal synchronization of slow waves is not caused by eye movements, it is usually treated in connection with a high degree of 'internal' concentration on certain mental operations (Ishihara and Yoshii, 1972; Fernandez et al., 1995) accompanied by reduced reactivity to external stimuli (Vredevelt and Magnus, 1977). In such cases, θ-amplitudes correlate with parameters of attention as well as with the character of mental task (Mizuki, 1987).

It is possible that in Factor Ia, the foregoing phenomena are somewhat generalized. This may reflect some special type of organization of mental processes in anterior areas. In our previous study with application of the same intellectual tests, spectral power in Δ, slow θ1 (4.0–5.5 Hz) and β (predominantly β2, 20.5–25.0 Hz) frequencies increased in frontal and anterior temporal areas, while in other areas, these parameters decreased in all the bands (including fast β2) (Lazarev, 1992).

As stated above, deceleration and synchronization of bioelectrical activity usually means some intensification of inhibitory processes (Rusalov and Bodunov, 1980). In case of Factor Ia, they are obviously active by nature since they get intensified during mental activity (as in the case of Factor III) against a background of EEG (Factor I) and psychological indicators of cerebral activation. These inhibitory processes are characteristic of anterior areas and apparently relate to some special selective and regulatory functions of frontal cortex. According to the results of the present research, they did not depend on 'nonspecific' mental efforts since their intensification was more expressed in matching rhymes (less difficult in comparison with mental arithmetic, according to subjective reports). On the other hand, such specificity of reaction during associative verbal activity may possibly be connected with some special mode of selectivity in successively organized verbal operations with certain inhibitory aspect of their neurodynamics. A left-side prevalence in augmentation of Factor Ia during matching rhymes may count in favour of such an interpretation.

It is not possible to exclude some contribution from uncontrolled eye movements to Factor Ia, although it is difficult to ascribe to them the obtained differences (especially interhemispheric ones) in this factor's values between two similar types of intellectual activity.

Comparison of the first and 'following' performances of two kinds of intellectual tasks demonstrates that the revealed 'specific' differences between verbal and arithmetic activity become apparent after repetition of the tasks when certain optimization and minimization of the functioning neuronal networks has apparently formed.

References

Basar, E., 1980. EEG-brain dynamics: relation between EEG and brain evoked potentials. Biomedical Press, Elsevier/North Holland, Amsterdam.

Bekhtereva, N.P., Bundzen, P.V., 1974. Neurophysiological organization of human mental activity. In: Bekhtereva, N.P. (Ed.), Neurophysiological Mechanisms of Human Mental Activity (in Russian). Nauka, Leningrad, pp. 42–60.

Bochkarev, V.K., Nikiforov, A.I., 1981. Application of linear models in the EEG investigations. Human Physiology, vol. 7 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 366–375.

Bochkarev, V.K., Lazarev, V.V., Nikiforov, A.I., Paniushkina, S.V., Severnyi, A.A., 1987. Clinical-electroencephalographic correlations in asthenic adynamic subdepressions. Zh. Nevropatol. Psikhiatr. 87, 564–570.

Brain Scan System, 1991. User's Guide. Neurotron, Moscow.

Bruneau, N., Roux, S., Guerin, P., Garreau, B., Lelord, G., 1993. Auditory stimulus intensity responses and frontal midline theta rhythm. Electroencephalogr. Clin. Neurophysiol. 86, 213–216.

Burgess, A., Gruzelier, J., 1993. Localization of cerebral function using topographical mapping of EEG: a preliminary validation study. Electroencephalogr. Clin. Neurophysiol. 87, 254–257.

Butler, S.R., Glass, A., 1974. Asymmetries in the electroencephalogram associated with cerebral dominance. Electroencephalogr. Clin. Neurophysiol. 36, 481–491.

Carter, W.R., Johnson, M.C., Borkovec, T.D., 1986. Worry: an electrocortical analysis. Adv. Behav. Res. Ther. 8, 193–204.

Darrow, C.W., 1947. Psychological and psychophysiological significance of the electroencephalogram. Psychol. Rev. 54, 157–168.

Darrow, C.W., Vieth, R.N., Wilson, J., 1957. Electroencephalographic 'blocking' and 'adaptation'. Science 126, 74–75.

Davidson, R.J., Chapman, J.P., Chapman, L.J., Henriques, J.B., 1990. Asymmetrical brain electrical activity discriminates between psychometrically-matched verbal and spatial tasks. Psychophysiology 27, 528–543.

Davis, P.A., 1941. The technique and evaluation of the EEG. J. Neurophysiol. 1, 92–114.

Dimond, S.J., Beaumont, G., 1972. A right hemisphere basis for calculation in human brain. Psychon. Sci. 26, 137–138.

Elul, R., 1971. The genesis of the EEG. Int. Rev. Neurobiol. 15, 227–272.

Etevenon, P., 1986. Applications and perspectives of EEG cartography. In: Duffy, F.H. (Ed.), Topographic Mapping of Brain Electrical Activity. Butterworths, Boston, pp. 113–141.

Etevenon, P., Samson-Dollfus, D., Kemali, D., Perris, C., 1982. In quest of the best spectral EEG parameters towards a multicentric consensus for measuring normality, psychopathology and psychotropic drug effects. In: Electrophysiological Correlates of Psychopathology. 3rd International Symposium of Clinical and Neurophysiological Aspects of Psychopathological Conditions. Stockholm, 28 June, 1981, Basel, pp. 28–38.

Etevenon, P., Tortrat, D., Bencelfat, C., 1985. Electroencephalographic cartography. II. By means of statistical group studies — Activation by visual attention. Neuropsychobiology 13, 141–146.

Fernandez, T., Harmony, T., Rodriguez, M., Bernal, J., Silva, J., Reyes, A., Marosi, E., 1995. EEG activation patterns during the performance of tasks involving different components of mental calculation. Electroencephalogr. Clin. Neurophysiol. 94, 175–182.

Gale, A., Spratt, G., Christie, B., Smallbone, A., 1975. Stimulus complexity, EEG abundance gradients, and detection efficiency in a visual recognition task. Br. J. Psychol. 66, 289–298.

Galeano, C., Roing, A., Sommer-Smith, J.A., 1964. Conditioning of subcortical telencephalic stimulation effects. Electroencephalogr. Clin. Neurophysiol. 17, 281–293.

Gassanov, U.G., 1988. Problems of internal inhibition. Usp. Fiziol. Nauk 19, 66–87.

Giannitrapani, D., 1969. EEG average frequency and intelligence. Electroencephalogr. Clin. Neurophysiol. 27, 480–486.

Giannitrapani, D., 1971. Scanning mechanisms and the EEG. Electroencephalogr. Clin. Neurophysiol. 30, 139–146.

Giannitrapani, D., 1982. Localization of language and arithmetic functions via EEG factor analysis. Res. Commun. Psychol., Psychiatry Behav. 7, 39–55.

Gille, H.-G., Ullsperger, P., Wieckmann, B., 1979. Changes in the spectral power density of the EEG while solving arithmetical tasks presented for limited periods. Act. Nerv. Super. (Praha) 21, 39.

Glanzer, M., Chapman, R.M., Clark, W.H., Bragdon, H.R., 1964. Changes in two EEG rhythms during mental activity. J. Exp. Psychol. 68, 273–283.

Glaria, A.R., Murray, A., 1985. Comparison of EEG monitoring techniques: an evaluation during cardiac surgery. Electroencephalogr. Clin. Neurophysiol. 61, 323–330.

Glass, A., 1967. Changes in the prevalence of alpha activity associated with the repetition, performance and magnitude of arithmetical calculations. Psychol. Forsch. 30, 250–272.

Gordon, H.W., Bogen, J.E., 1974. Hemispheric lateralization of singing after intracarotid sodium amylobarbitone. J. Neurol., Neurosurg. Psychiatry 37, 727–738.

Gruzelier, J.H., Liddiard, D.M., Wilson, L., Schellensberg, R., Davis, L., Peters, E., 1988. Validation of EEG topographical mapping with neuropsychological tests. In: Samson-Dollfus, D. (Ed.), Statistics and Topography in Quantitative EEG. Elsevier, Amsterdam, pp. 110–118.

Gruzelier, J., Liddiard, D., Davis, L., Wilson, L., 1990. Topographical EEG differences between schizophrenic patients and controls during neuropsychological functional activation. Int. J. Psychophysiol. 8, 275–282.

Gundel, A., Wilson, G.F., 1992. Topographical changes in the ongoing EEG related to the difficulty of mental tasks. Brain Topogr. 5, 17–25.

Harman, H.H., 1967. Modern Factor Analysis. University of Chicago Press, Chicago.

Hecaen, H., Angelergues, R., Houllier, S., 1961. Les varietes cliniques des acalculies au cours des lesions retrorolandiques: approche statistique du probleme. Rev. Neurol. 105, 85–103.

Ingvar, D.H., 1987. Evidence for frontal/prefrontal cortical disjunction in chronic schizophrenia: the phenomenon of 'Hypofrontality' reconsidered. In: Biological Perspectives of Schizophrenia. Report of the Dahlem Workshop, Berlin, 26–31 October 1986. J. Wiley and Sons, Chichester, pp. 237–253.

Inouye, T., Shinosaki, K., Iyama, A., Matsumoto, Y., 1993. Localization of activated areas and directional EEG patterns during mental arithmetic. Electroencephalogr. Clin. Neurophysiol. 86, 224–230.

Ishihara, T., Yoshii, N., 1972. Multivariate analytic study of EEG and mental activity in juvenile delinquents. Electroencephalogr. Clin. Neurophysiol. 33, 71–80.

Itil, T.M., Shapiro, D.M., Eralp, E., Akman, A., Itil, K.Z., Garbizu, C., 1985. A new brain function diagnostic unit, including the dynamic brain mapping of computer analysed EEG, evoked potentials and sleep. New Trends Exp. Clin. Psychiatry 1-2, 107–177.

Itil, T.M., Mucci, A., Eralp, E., 1991. Dynamic brain mapping methodology and application. Int. J. Psychophysiol. 10, 281–291.

Iznak, A.F., 1989. Modulation of sensorimotor activity of man against the background of EEG alpha rhythm. In: Iznak, A.F. (Ed.), Problems of Developing Scientific Research in the Field of Mental Health (in Russian). National Mental Health Research Centre, Moscow, pp. 3–24.

Iznak, A.F., Chayanov, N.V., 1989. Subjective correlates of human EEG alpha bursts during visual-motor operator activity. In: Iznak, A.F. (Ed.), Problems of Developing Scientific Research in the Field of Mental Health (in Russian). National Mental Health Research Centre, Moscow, pp. 24–30.

John, E.R., Schwartz, E.L., 1978. The neurophysiology of information processing and cognition. Ann. Rev. Psychol. 29, 1–29.

John, E.R., Prichep, L.S., Chabot, R.J. 1989. Quantitative electrophysiological maps of mental activity. In: Basar, E., Bullock, T.H. (Eds.), Brain Dynamics 2. Springer, Berlin, pp. 316–330.

Kakizaki, T., 1987. Occipital midline EEG and subjective rating of task difficulty as indices of mental task strain. Eur. J. Appl. Physiol. Occup. Physiol. 56, 163–168.

Keirn, Z.A., Aunon, J.I., 1990. Man-machine communication through brain-wave processing. IEEE Eng. Med. Biol. 9, 55–57.

Kennedy, J.L., Gottsdaker, R.M., Armington, J.C., Gray, F.E., 1948. A new electroencephalogram associated with thinking. Science 108, 527–529.

Khomskaya, E.D., 1972. Brain and Activation (in Russian). Moscow University Press, Moscow.

Khomskaya, E.D., 1980. Psychological investigations in the USSR of the problem of interhemispheric asymmetry of the brain. Psikhol. Zh. 1, 116–120.

Klimesch, W., Schimke, H., Schwaiger, J., 1994. Episodic and semantic memory: an analysis in the EEG theta and alpha band. Electroencephalogr. Clin. Neurophysiol. 91, 428–441.

Klingberg, F., 1971. Hypersynchrony and learning. In: Adam, G. (Ed.), Biology of Memory. Akademiai Kiado, Budapest, pp. 299–305.

Klingberg, F., 1977. EEG and regulation of sensory input into cerebral cortex. In: Rusinov, V.S. (Ed.), Functional Meaning of the Electrical Processes of the Brain (in Russian). Nauka, Moscow, pp. 307–312.

Kostelianets, N.B., Kamenkovich, V.M., Novikova, G.R., Kulikov, M.A., 1988. Interhemispheric differences in dynamics of identification of images. Human Physiology, vol. 14 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 402–406.

Kratin, Yu., G., 1967. Electrical Reactions of the Brain to the Inhibitory Signals (in Russian). Nauka, Leningrad.

Lazarev, V.V., 1978. Changes of functional state of the brain during motor and intellectual activity. In: Psychological Aspects of Human Activity. II. Industrial Psychology and Psychology of Labour (in Russian). Institute of Psychology, USSR Academy of Sciences, Moscow, pp. 103–114.

Lazarev, V.V., 1985. On interconnection of certain parameters of the human EEG. Zh. Vyssh. Nervn. Deyat. 35, 625–634.

Lazarev, V.V., 1986a. Electroencephalographic characteristics of intellectual activity in astheno-adynamic subdepressions. Zh. Nevropatol. Psikhiatr. 86, 1807–1813.

Lazarev, V.V., 1986b. Factorial structure of the principal EEG parameters during intellectual activity. I. Local characteristics of nonhomogeneity of functional states. Human Physiology, vol. 12 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 375–382.

Lazarev, V.V., 1987. Factorial structure of the principal EEG parameters during intellectual activity. II. Topography of functional states. Human Physiology, vol. 13 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 9–12.

Lazarev, V.V., 1988. Dynamic values of the EEG factors in the human perception of sound stimuli. Zh. Vyssh. Nervn. Deyat. 38, 403–410.

Lazarev, V.V., 1989. Mental activity and neurodynamics of the brain functional states. In: Iznak, A.F. (Ed.), Problems of Developing Scientific Research in the Field of Mental Health (in Russian). National Mental Health Research Centre, Moscow, pp. 30–66.

Lazarev, V.V., 1992. Informative value of various approaches to EEG mapping in the investigation of human mental activity. Human Physiology, vol. 18, no. 6 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 49–57.

Lazarev, V.V., Sviderskaya, N.E., Khomskaya, E.D., 1977a. Changes in spatial synchronization of biopotentials during various types of intellectual activity. Human Physiology, vol. 3 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 187–194.

Lazarev, V.V., Sviderskaya, N.E., Khomskaya, E.D., 1977b. Spatial synchronization of the cortical biopotentials during intellectual strain in normals and in the patients with local lesions of the brain. In: Luria, A.R., Khomskaya, E.D. (Eds.), The Problems of Neuropsychology (in Russian). Nauka, Moscow, pp. 92–109.

Lebedeva, I.S., Lazarev, V.V., 1989. Some psychophysiological characteristics of audiomotor reactions and the structure of the EEG in normal subjects and atypical juvenile depressive patients. In: Iznak, A.F. (Ed.), Problems of Developing Scientific Research in the Field of Mental Health (in Russian). National Mental Health Research Centre, Moscow, pp. 66–71.

Legewie, H., Simonova, O., Creutzfeld, O.D., 1969. EEG changes during performance of various tasks under open- and close-eyed conditions. Electroencephalogr. Clin. Neurophysiol 27, 470–479.

Livanov, M.N., 1977. Spatial Organization of Cerebral Processes. Wiley, New York.

Lorig, T.S., 1986. EEG and task performance: a comparison of three analytic techniques. Physiol. Psychol. 14, 130–132.

Luria, A.R., 1966. Higher Cortical Functions in Man. Basic Books, New York.

Makeig, S., Inlow, M., 1993. Lapses in alertness: coherence of fluctuations in performance and EEG spectrum. Electroencephalogr. Clin. Neurophysiol. 86, 23–35.

Matousek, M., Volavka, Y., Roubicek, Y., Chamrod, V., 1969. The autocorrelation and frequency analysis of the EEG compared with CYSR at different level of activation. Brain Res. 15, 507–514.

Milner, B., Petrides, M., 1985. Frontal lobes and the temporal organization of memory. Hum. Neurobiol. 4, 137–142.

Mizuki, Y., 1987. Frontal lobe: mental functions and EEG. Am. J. EEG Technol. 27, 91–101.

Monakhov, K.K., Perris, C., Bochkarev, V.K., Knorring, L.V., Nikiforov, A.I., 1979. Functional interhemispheric differences in relation to various psychopathological components of the depressive syndromes. Neuropsychobiology 5, 143–155.

Monakhov, K.K., Bochkarev, V.K., Nikiforov, A.I., 1983. Applied Aspects of Neurophysiology in Psychiatry (in Russian). Meditsina, Moscow.

Mundy-Castle, A.C., 1957. The electroencephalogram and mental activity. Electroencephalogr. Clin. Neurophysiol. 9, 643–655.

Nebylitsyn, V.D., 1963. Electroencephalographic study of 'strength' characteristic of nervous system and of balance of nervous processes in man by application of factorial analysis. In: Typological Features of Human Higher Nervous Activity, vol. 3 (in Russian). Prosveschenie, Moscow.

Nebylitsyn, V.D., 1966. Principal Properties of the Human Nervous System (in Russian). Prosveschenie, Moscow.

Nevskaya, A.A., Leushina, L.I., Pauk, V.A., Makulov, V.B., 1989. Interhemispheric differences in spatial-frequency analysis of image. Human Physiology, vol. 15, no. 6 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 16–23.

Nikiforov, A.I., 1981. Methodological aspects of the application of mathematical methods in EEG analysis in clinical neurophysiology. Human Physiology, vol. 7 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 359–365.

Nikiforov, A.I., Bochkarev, V.K., 1974. Primary analysis of the human EEG by minicomputer. Zh. Nevropatol. Psikhiatr. 74, 288–291.

Nunn, C.M.H., Osselton, J.W., 1974. The influence of the EEG alpha on the perception of visual stimuli. Psychophysiology 11, 294–303.

Pavlov, I.P., 1951. Complete Works, vol. 4 (in Russian). USSR Academy of Sciences, Moscow-Leningrad.

Pavlova, L.P., 1979. Cerebral organization of the process of a forming of mental activity. Human Physiology, vol. 5 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 727–734.

Petsche, H., Rappelsberger, P., Rockberger, H., 1988. Sex differences in ongoing EEG: Probability mapping at rest and during cognitive tasks. In: Pfurtscheller, G., Lopes da Silva, F.H. (Eds.), Functional Brain Imaging. Hans Huber, Toronto, pp. 161–169.

Petsche, H., Etlinger, S.C., Filz, O., 1993. Brain electrical mechanisms of bilingual speech management: an initial investigation. Electroencephalogr. Clin. Neurophysiol. 86, 385–394.

Pfurtscheller, G., 1992. Event related synchronization (ERS): an electrophysiological correlate of cortical areas at rest. Electroencephalogr. Clin. Neurophysiol. 83, 62–69.

Pfurtscheller, G., Steffan, J., Maresch, H., 1988. ERD mapping and functional topography: Temporal and spatial aspects. In: Pfurtscheller, G., Lopes da Silva, F.H. (Eds.), Functional Brain Imaging. Hans Huber, Toronto, pp. 117–130.

Qureshi, R., Dimond, S.J., 1979. Calculation and the right hemisphere. Lancet I, 322.

Ratanova, T.A., 1983. Differential loudness sensitivity, strength of nervous system and psychophysical scales of loudness. Vopr. Psikhol. no. 1, 122–129.

Ray, W.J., Cole, H.W., 1985. EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. Science 228, 750–752.

Roland, P.E., 1985. Cortical organization of voluntary behaviour in man. Hum. Neurobiol. 4, 155–167.

Rusalov, V.M., Bodunov, M.V., 1980. On factor structure of integral electroencephalographic parameters of man. In: Rusalov, V.M., Golubeva, E.A. (Eds.), Psychophysiological Investigations of Intellectual Self-Regulation and Activity (in Russian). Nauka, Moscow, pp. 94–113.

Rusinov, V.S., Grindel, O.M., Boldyreva, G.N., Vakar, E.M., 1987. Biopotentials of the Human Brain. Mathematical Analysis (in Russian). Meditsina, Moscow.

Schacter, D.L., 1977. EEG theta waves and psychological phenomena: a review and analysis. Biol. Psychol 5, 47–82.

Simernitskaya, E.G., Blinkov, S.M., Yakovlev, A.I., Kopeel, L.V., 1978. On dominance of hemispheres in perception of numbers. Human Physiology, vol. 4 (a translation of Fiziol. Cheloveka). Plenum, New York, pp. 779–783.

Sokolov, E.N., 1963. Higher nervous functions: the orienting reflex. Ann. Rev. Physiol. 25, 545–580.

Sviderskaya, N.E., 1977. Slow components of EEG in the human mental activity. Zh. Vyssh. Nervn. Deyat. 27, 824–830.

Überla, K., 1977. Faktorenanalyse. Eine systematische Einführung für Psychologen, Mediziner Wirtschafts und Sozialwissenschaftler. Springer Verlag, Berlin.

Vogel, W., Broverman, D.M., Klaiber, E.L., 1968. EEG and mental abilities. Electroencephalogr. Clin. Neurophysiol. 24, 166–175.

Vredevelt, J.W., Magnus, O., 1977. Marked frontal theta-rhythm. Electroencephalogr. Clin. Neurophysiol. 43, 548.

Zeller, G., 1986. Multivariate beziehungsanalysen zu psychologischen parametern und veranderungen der hirnelectrischen wachaktivitat im rahmen visuell er suchprozesse. Z. Psychol. 194, no. 71, 39–61.

Zhirmunskaya, E.A., Makarova, G.V., 1975. Relation of separate waves' mean level of fronts' asymmetry to structure of human EEG. In: Sokolov, E.N. (Ed.), Functional States of the Brain (in Russian). Moscow University Press, Moscow, pp. 113–118.

Zhirmunskaya, E.A., Gutman, S.R., Maslov, V.K., Mezentsev, V.V., Ustikova, N.S., 1977. On identification of subject's states by characteristics of electroencephalogram. In: Rusinov, V.S. (Ed.), Functional Meaning of the Electrical Processes of the Brain (in Russian). Nauka, Moscow, pp. 274–282.